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ABSTRACT

An experimental study of inclusive hadron production by neutrinos from protons is reported. The data are based on a sample of approximately 450 charged current events in the energy range 15-200 GeV obtained using the 15-Ft. bubble chamber filled with hydrogen. Transverse momentum distributions and distributions in  $z = p_{\text{lab}}/\nu$  are presented for positive and negative hadrons.

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## I. INTRODUCTION

In a previous paper<sup>1</sup> results of a study of the reaction

$$\nu_{\mu} p \rightarrow \mu^{-} + \text{hadrons} \quad (1)$$

were presented based on a sample of approximately 450 events in the energy range 15-200 GeV obtained using the 15-Ft. bubble chamber at Fermilab. In this paper the results of a study of some features of the reaction

$$\nu_{\mu} p \rightarrow \mu^{-} h + \text{hadrons} \quad (2)$$

where  $h$  represents any single hadron are presented based on the same event sample.

## II. ANALYSIS

In this experiment as has been discussed in Ref. 1 the neutrino energy  $E$ , and the direction of the 3-momentum transfer are not known precisely. For this reason in this study attention is concentrated on the component of the transverse momentum of the hadron measured out of the plane defined by the muon and the incoming neutrino. This variable is referred to as  $p_T \text{ out}$  and should be unaffected by uncertainties due to missing neutrals.

In this experiment it is not generally possible to make a unique mass assignment for the charged tracks except at low momentum. For this reason in this study no attempt has been made to separate the data for different hadron masses. Positive hadrons are expected to be predominantly a mixture of pions and

protons. Negative hadrons are expected to be predominantly pions. The variable  $z$  is defined by the relation

$$z = p_{\text{lab}}/v \quad (3)$$

where  $p_{\text{lab}}$  is the momentum of the hadron in the laboratory frame and  $v$  is the energy transfer to the hadrons.

The methods of analysis used in this study are identical to the methods outlined in Ref. 1. The data cuts discussed in Ref. 1 have been made and in addition events with  $y > 0.9$  ( $y = v/E$ ) have been excluded. This cut is expected to eliminate more than 90% of the background due to antineutrino events which might otherwise have an important effect on the distributions. Within these cuts the residual background of antineutrino events in the sample estimated to be less than 0.5%.

### III. RESULTS AND CONCLUSIONS

Figure 1a shows the mean value of  $p_{T \text{ out}}^2$  for positive hadrons as a function of  $z$ . Figure 1b shows the same thing for negative hadrons. At small  $z$  ( $z < 0.2$ ) the mean value of  $p_{T \text{ out}}^2$  increases with increasing  $z$ . For  $z < 0.2$  the mean value of  $p_{T \text{ out}}^2$  increases with increasing  $z$ . For  $z > 0.2$  there is no strong  $z$ -dependence and the two data sets are consistent. For  $z > 0.2$  the data gives

$$\langle p_{T \text{ out}}^2 \rangle = 0.122 \pm 0.006 \text{ GeV}^2 \quad (4)$$

for positives and negatives combined. For fixed  $z$  the mean value of  $p_{T \text{ out}}^2$  is found to be essentially independent of neutrino energy.

The transverse momentum  $p_T$  of hadrons relative to the direction of the 3-momentum transfer has been measured in electron and muon scattering experiments.<sup>1,3</sup> It has been observed that the  $p_T$  distribution can be described by a relation of the form

$$dN/dp_T^2 \propto e^{-bp_T^2} \quad (5)$$

If the hadrons are produced with azimuthal symmetry about the direction of the 3-momentum transfer then (5) implies

$$dN/dp_{T \text{ out}}^2 \propto e^{-bp_{T \text{ out}}^2} \quad (6)$$

with  $b = [2 \langle p_{T \text{ out}}^2 \rangle]^{-1} \quad (7)$

Using Eq. 7) the result (4) implies  $b = 4.10 \pm 0.20 \text{ GeV}^{-2}$  for  $z > 0.2$ . Figure 2a shows the distribution  $dN/dp_{T \text{ out}}^2$  plotted as a function of  $p_{T \text{ out}}^2$  for positive hadrons with  $z > 0.2$ . Figure 2b shows the same thing for negative hadrons. In each case the straight line which has been normalized to the data is the relation (6) with  $b = 4.1 \text{ GeV}^{-2}$ . We conclude that the relation (6) provides a good description of our data

over the range  $p_{T \text{ out}}^2 = 0.01 - 1.0 \text{ GeV}^2$ . Note that if the data for smaller  $z$  are included then values for  $b$  in the range 5-6  $\text{GeV}^{-2}$  are obtained. These results appear to be consistent with the measurements made in electron and muon scattering experiments<sup>2</sup>,

Figures 3a and 3b show the  $z$  distributions  $dN/dz$  for positive and negative hadrons respectively for events in the energy range 15-30 GeV. The  $z$  distribution  $dN/dz$  measures the number of hadrons produced with momentum fraction  $z$ , per unit  $z$ , per event. Figures 3c and 3d show the same thing for events in the energy range 30-200 GeV. In each case the distribution is peaked to smaller  $z$  at the higher energies.

In the quark parton model  $z$ -distributions measured in neutrino scattering experiments at sufficiently high energy have a simple interpretation.<sup>3</sup> If we ignore the contribution of antiquarks and strange quarks in the proton then the distributions  $dN/dz$  for positive and negative hadrons represent the probability that a recoiling  $u$ -quark produces a positive or negative hadron with momentum fraction  $z$ . Similarly in electron proton scattering one might expect that the recoiling quark should be a  $u$ -quark, at least predominantly, and that the distribution of forward hadrons in electron proton and neutrino proton scattering might be similar. In figures 3a-3d the broken points show the corresponding data<sup>5</sup> for electron proton scattering taken from Ref. 2. While the neutrino data and the electron data are qualitatively similar it is apparent that the production of positive hadrons in the neutrino reaction is more copious

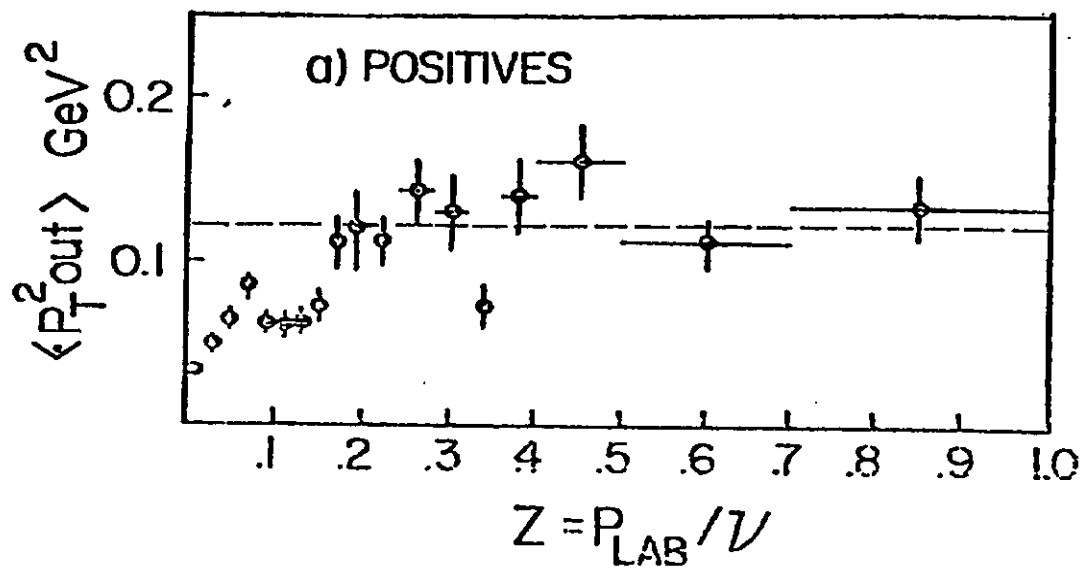
than in the electron reaction and there is some indication that the reverse is true for negative hadron production. The discrepancies are particularly apparent for large  $z$  and at low energy.

We thank the members of the neutrino laboratory at Fermilab and the scanning and measuring staffs in our respective laboratories for their contribution to this experiment.

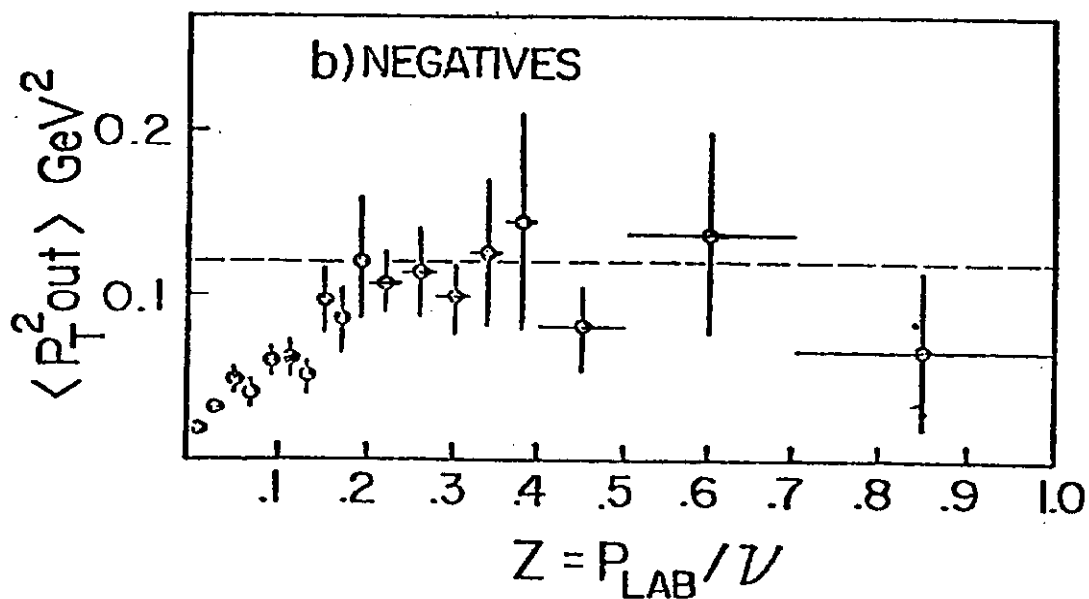
#### REFERENCES

- <sup>1</sup>J. P. Berge et al., (to be published).
- <sup>2</sup>J. T. Dakin et al., Phys. Rev. D10 1401, 1974.
- <sup>3</sup>L. W. Mo, Lepton Photon Symposium SLAC 1975.
- <sup>4</sup>R. P. Feynman, Photon-Hadron Interactions (Benjamin, New York 1972).
- <sup>5</sup>The electron data are actually plotted against  $x = P_L/P_L \text{ max}$  measured in the center of mass. In making this comparison we ignore the small difference between  $x$  and  $z$  for  $x > 0.1$ . The electron data shown in figures 3a-3d is plotted for a range in 4-momentum transfer squared given by  $Q^2 = 2-3 \text{ GeV}^2$  and a range in hadron invariant mass squared given by  $W^2 = 12-30 \text{ GeV}^2$ .





(a)



(b)

Fig. 1: The mean value of  $p_{T \text{ out}}^2$  plotted as a function of  $z$  for a) positive hadrons and b) negative hadrons. The straight line corresponds to  $\langle p_{T \text{ out}}^2 \rangle = 0.122 \text{ GeV}^2$  and represents the mean of the data for  $z > 0.2$ .

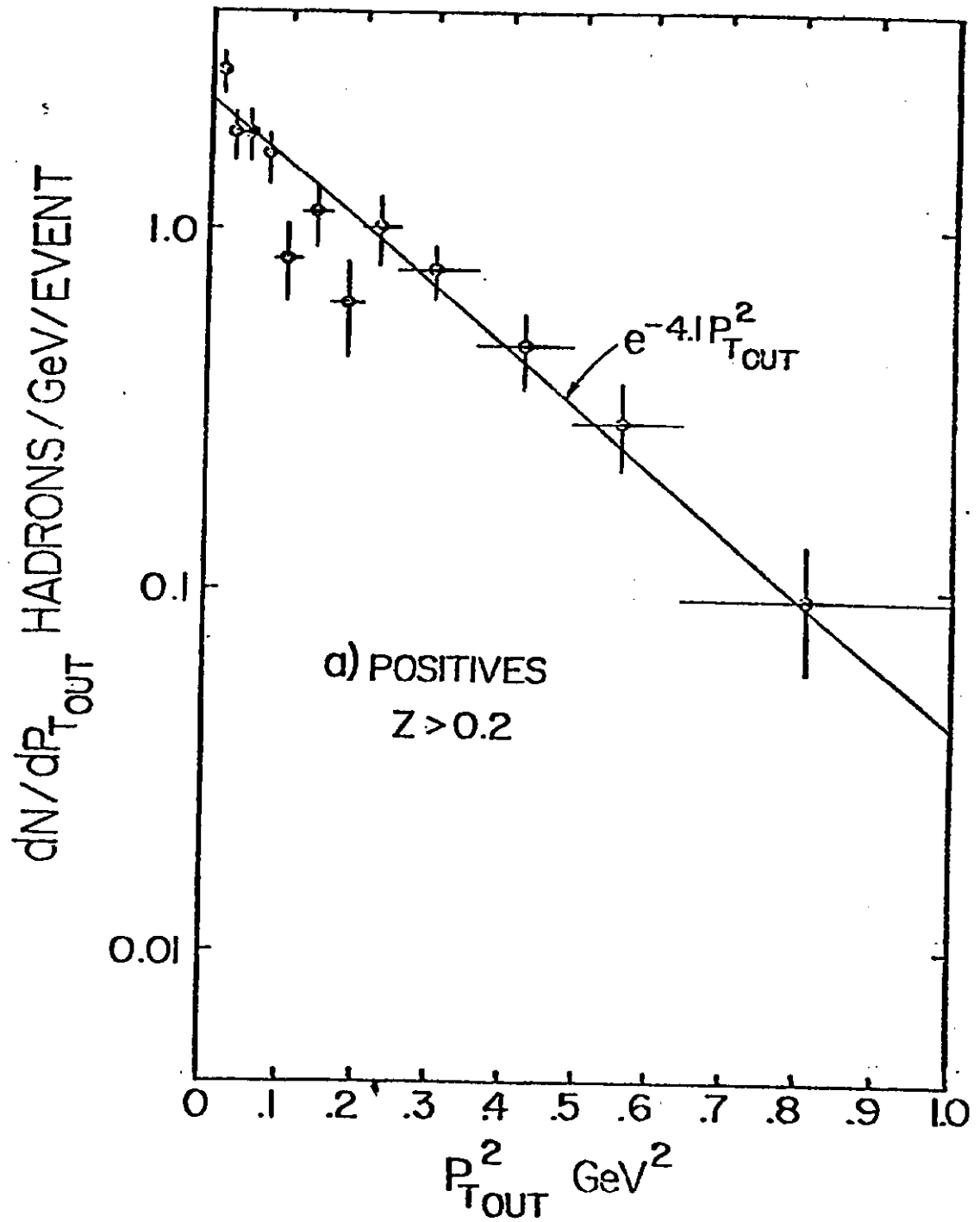


Fig. 2(a). The distribution  $dN/p_{T\text{out}}$  for  $z > 0.2$  plotted as a function  $p_{T\text{out}}^2$  for positive hadrons. The straight line shows the expected distribution (6) for  $b = 4.1 \text{ GeV}^{-2}$ .

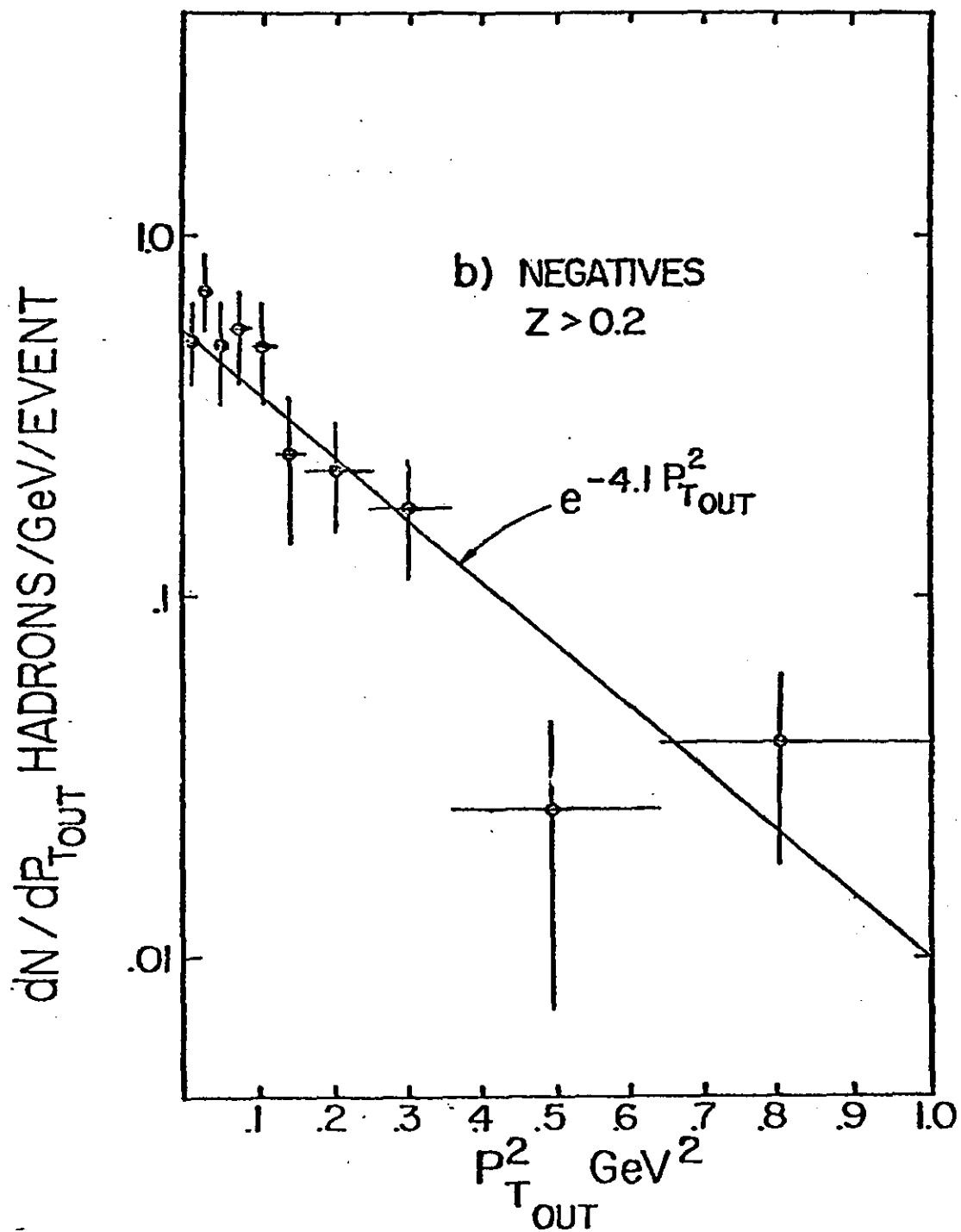


Fig. 2(b). The distribution  $dN/p_{T\text{OUT}}^2$  for  $z > 0.2$  plotted as a function  $p_{T\text{OUT}}^2$  for negative hadrons. The straight line shows the expected distribution (6) for  $b = 4.1 \text{ GeV}^{-2}$ .

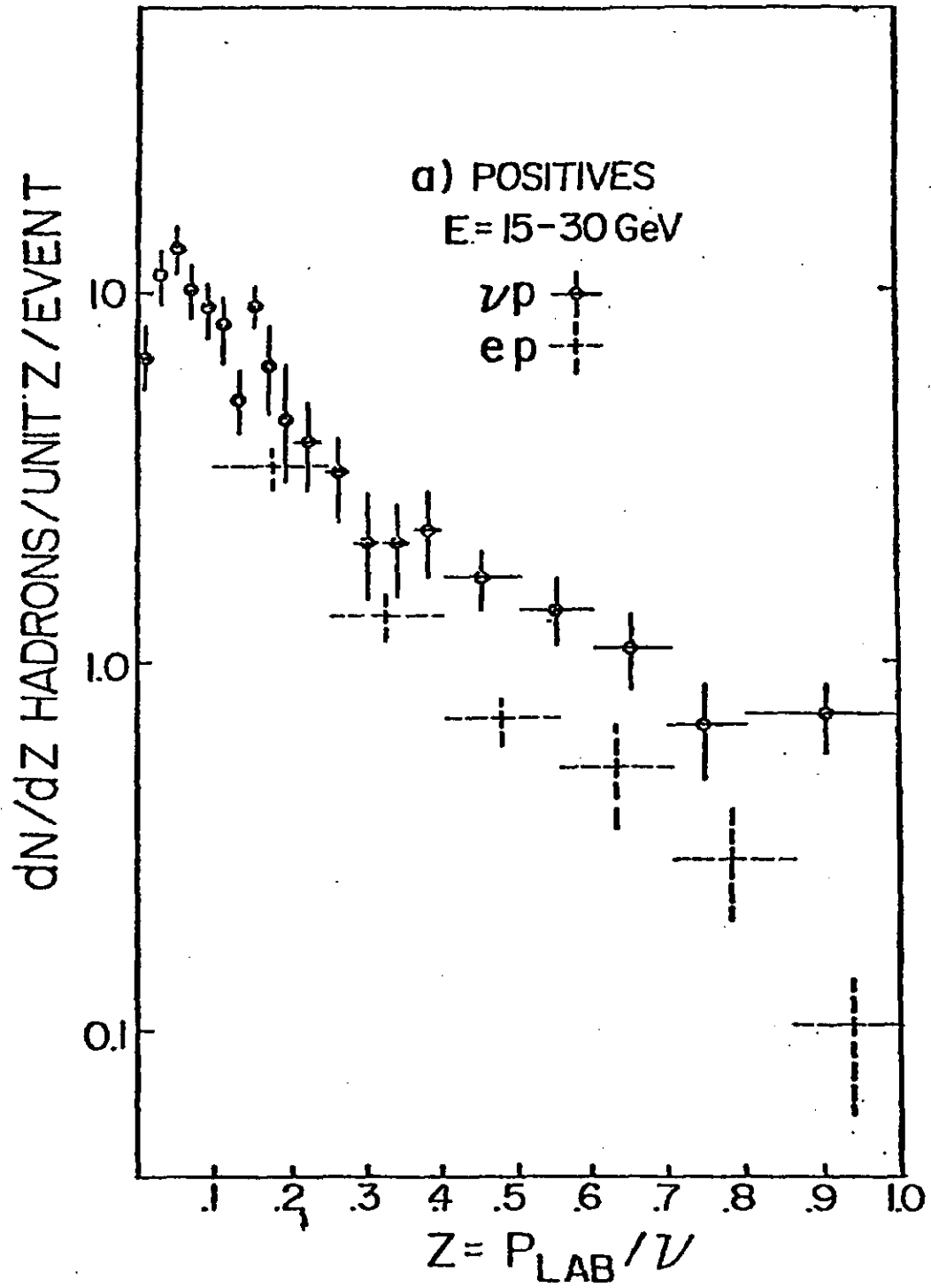


Fig. 3(a). The distributions  $dN/dz$  for positive hadrons for events with  $E = 15-30$  GeV. The broken data points represent ep data from Ref. 2.

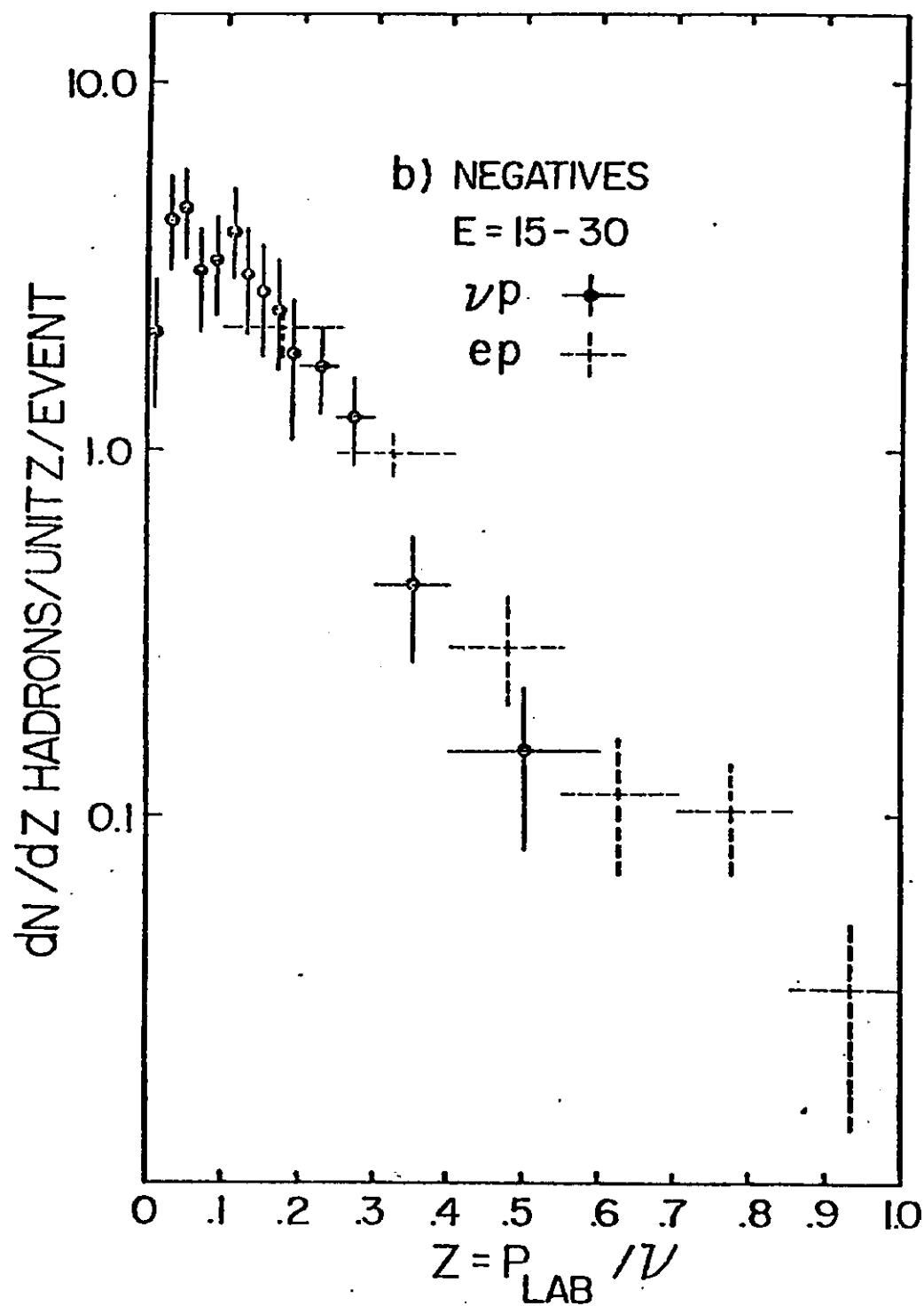


Fig. 3(b). The distributions  $dN/dz$  for negative hadrons for events with  $E = 15-30$  GeV. The broken data points represent ep data from Ref. 2.

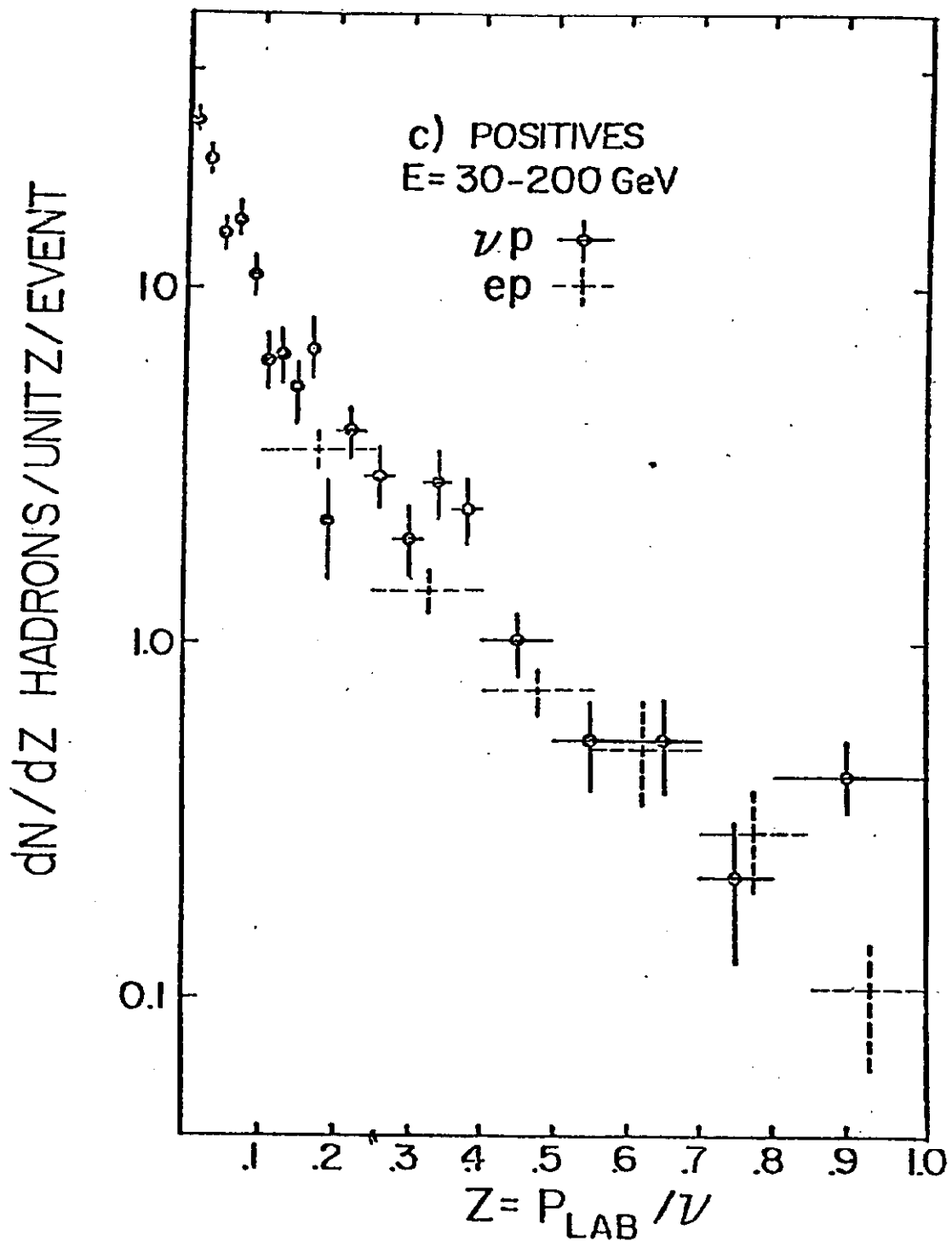


Fig. 3(c). The distributions  $dN/dz$  for positive hadrons for events with  $E = 30-200$  GeV. The broken data points represent ep data from Ref. 2.

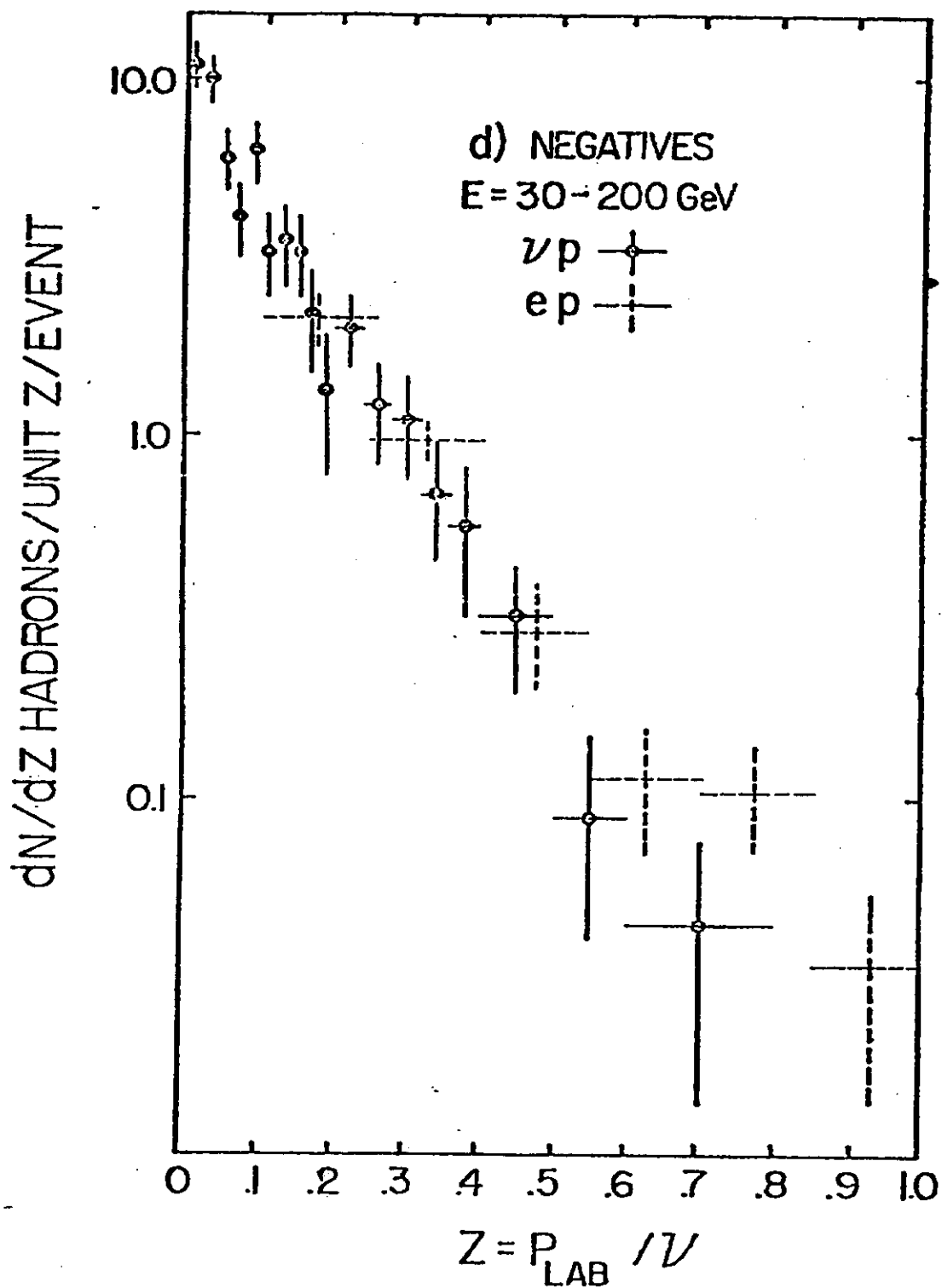


Fig. 3(d). The distributions  $dN/dz$  for negative hadrons for events with  $E = 30-200$  GeV. The broken data points represent ep data from Ref. 2.